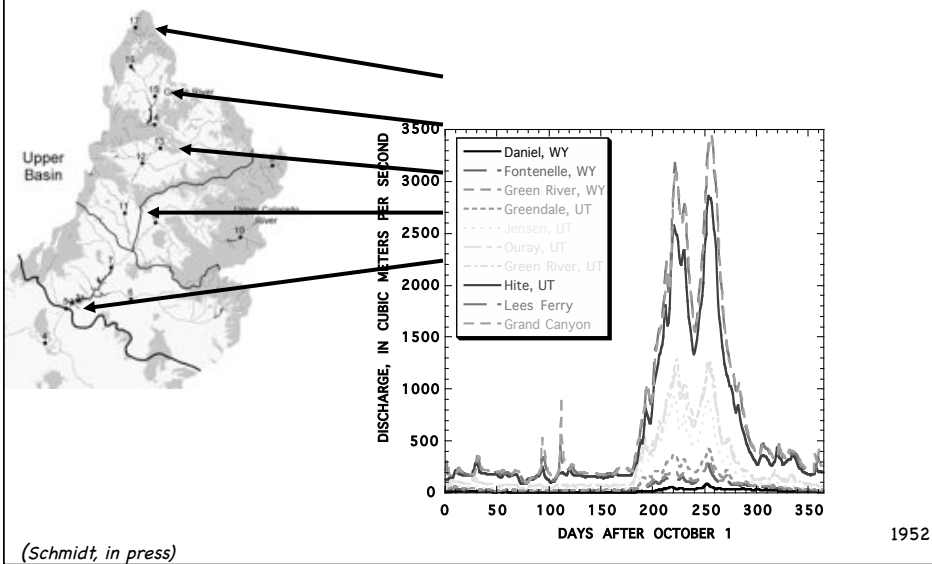
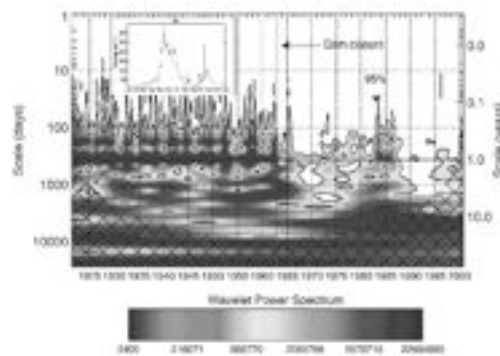
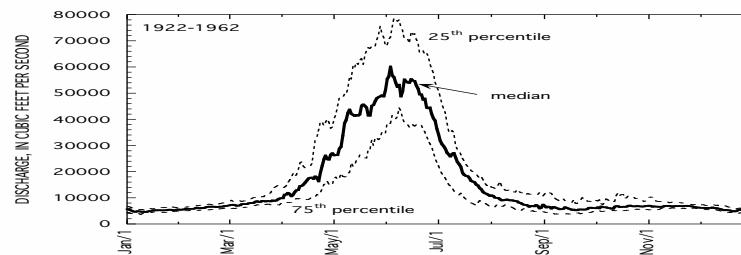


## High Flows in Grand Canyon

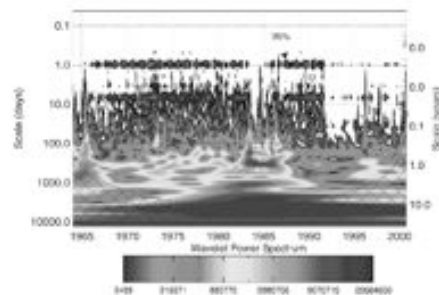
***The natural snowmelt flood through Grand Canyon came from the distant Rocky Mountains***

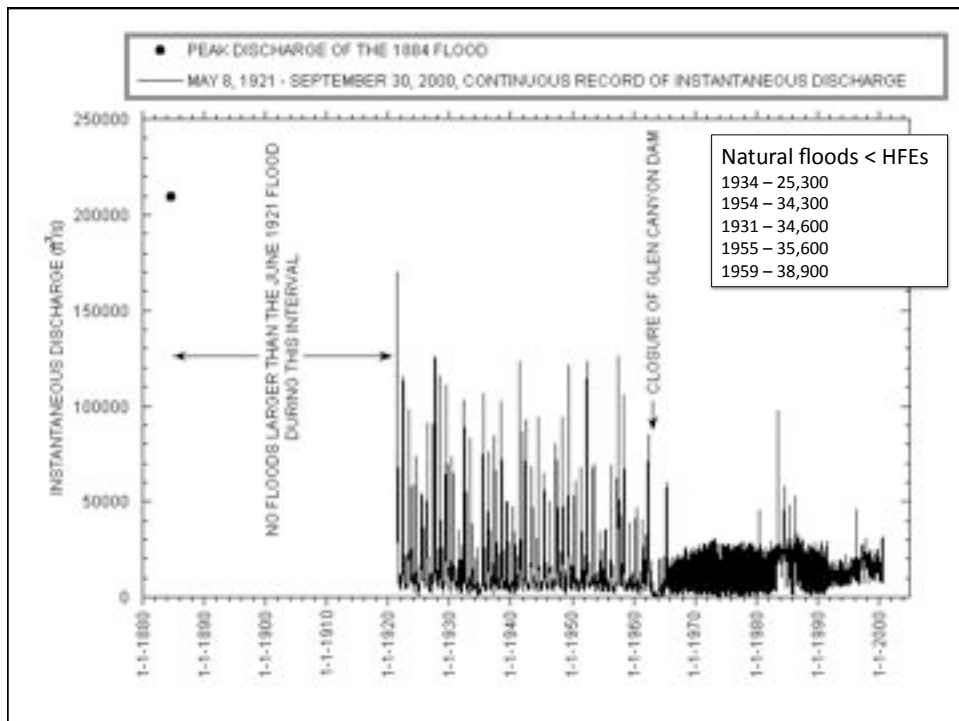
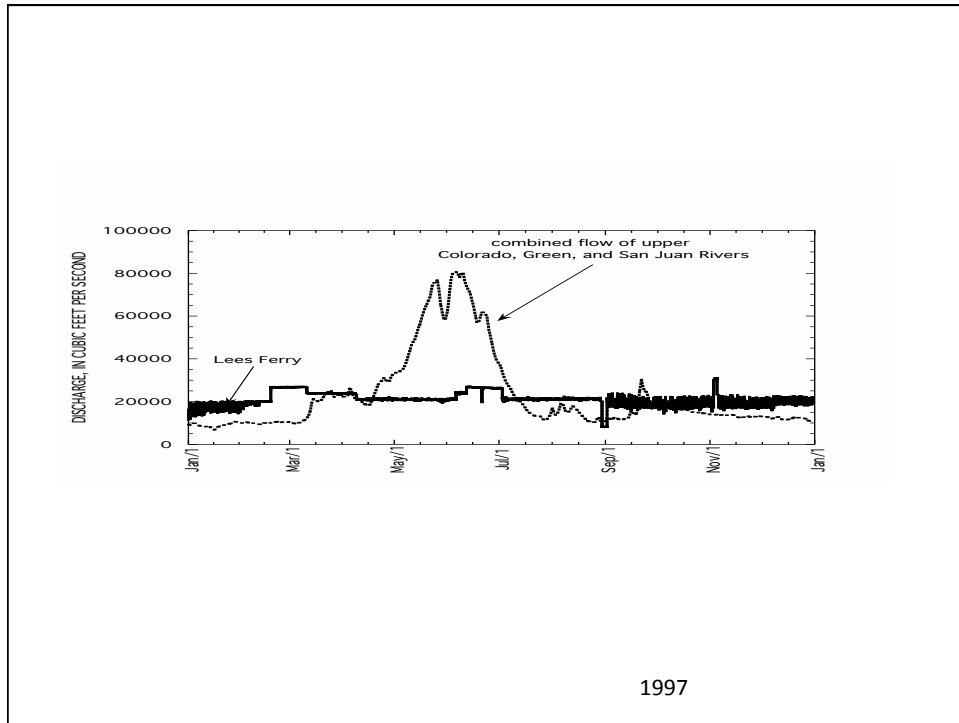


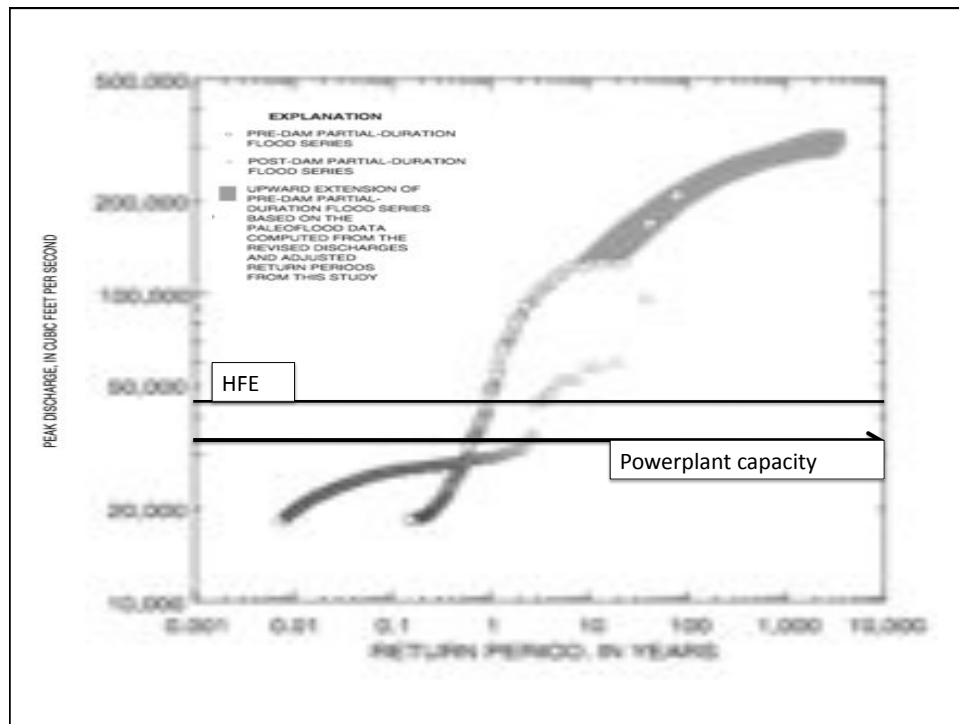


Wavelet power spectrum applied to  
Lees Ferry gaging record

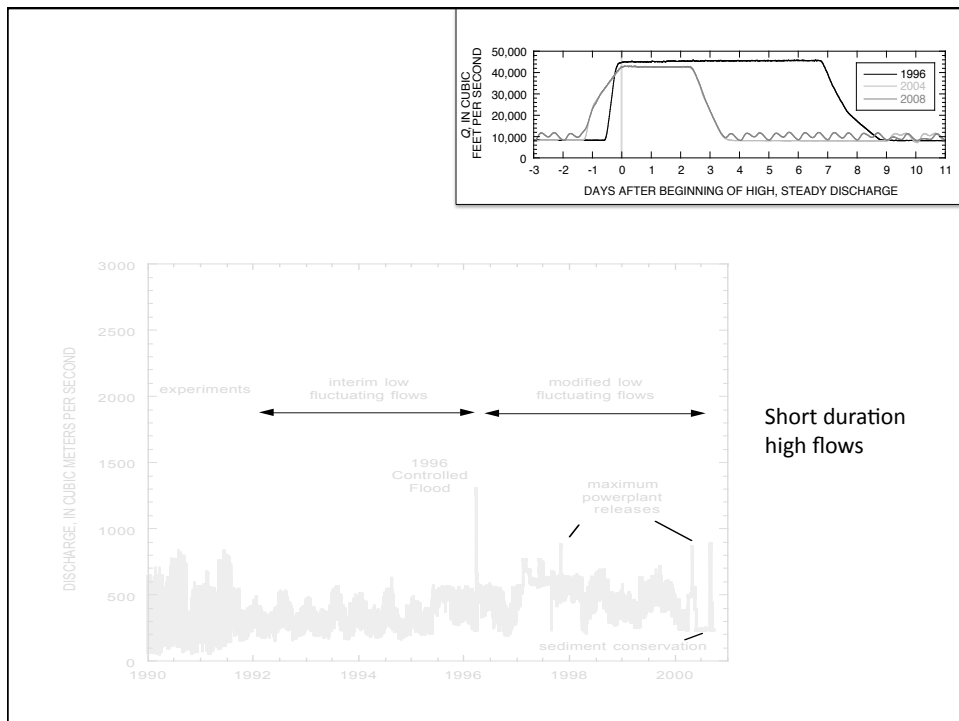
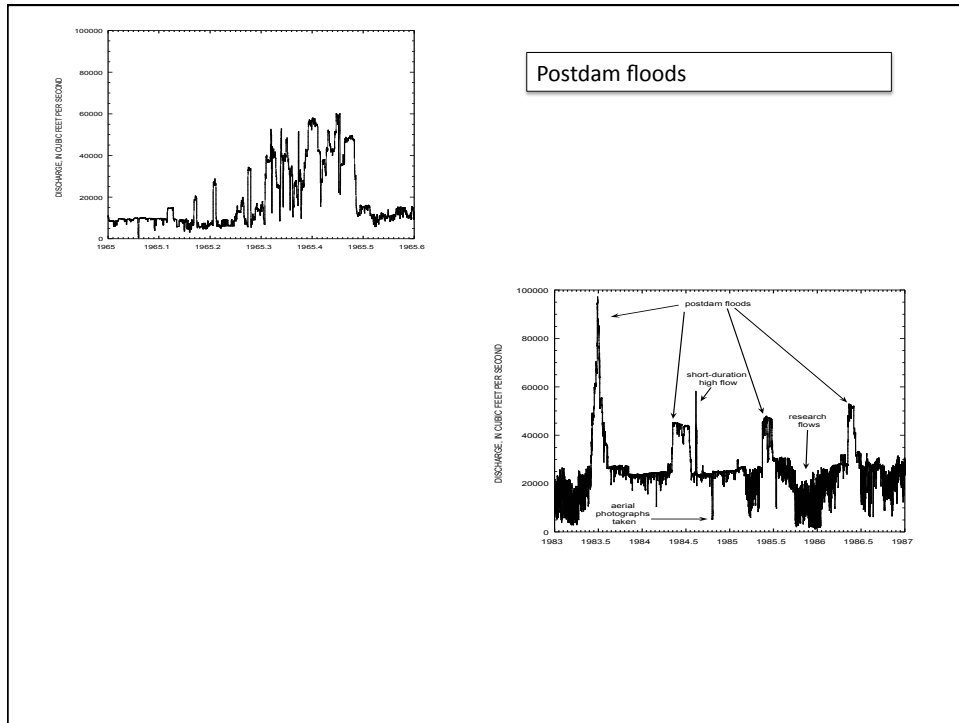
The annual spring snowmelt flood  
was the most significant annual  
disturbance to the aquatic  
ecosystem







Postdam floods					Short duration high flows			
	Number of consecutive days mean daily discharge exceeded 31,500 cubic feet per second <sup>1</sup>	Dates	Instantaneous peak, in cubic feet per second	purpose	Number of consecutive days mean daily discharge exceeded 31,500 cubic feet per second <sup>1</sup>	Dates	Instantaneous peak, in cubic feet per second	purpose
1965	34	May 21 - June 25	60,200	reservoir equalization and channel cleaning	7	May 4 - May 11		reservoir equalization and channel cleaning
1980					6	June 24 - July 1	44,800	spillway test
1983	68	June 3 - August 10	97,300	excess runoff				
1984	76	May 5 - July 20		excess runoff	3	August 12-15	58,200	spillway test
1985	39	May 17 - June 28	47,900	excess runoff				
1986	46	May 8 - June 24	53,200	excess runoff				
1996					8	March 26 - April 2	45,900	high-flow experiment
2004					3	November 22 - 24	42,500	high-flow experiment
2008					3	March 6 - 8	42,800	high-flow experiment



## Longstanding research themes and uncertainties in Grand Canyon research

Sediment Supply to the Colorado River

Sand and Mud

Coarse Sediment

Large-Scale Organization of the Colorado River and Its Valley

Flow Patterns, Hydraulics, and the Location and Characteristics of Eddy Sandbars

Development of Numerical Models

Large-Scale Controls on Fine Sediment Transport

Fine Sediment Mass Balance

Adjustment of the Channel Bed at Annual and Decadal Timescales

Adjustment of Sandbars at Annual and Decadal Timescales

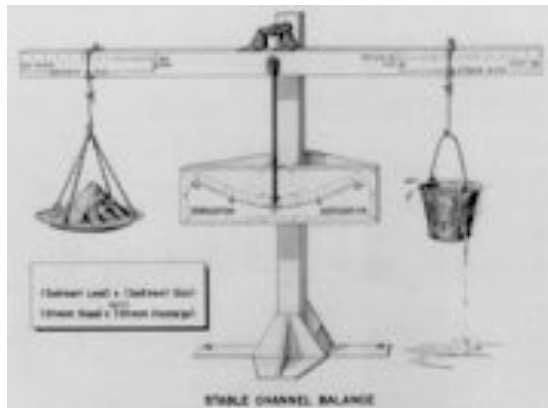
Short and Long-term Changes in Eddy Bars

Erosion of Eddy Sandbars

Spatial Variability in Patterns of Sandbar Change

Glen Canyon Dam has perturbed the sediment supply and sediment transporting flows

$$Q_s D \propto Q S$$



Borland's  
illustration of Lane's  
(1955) concept,  
drawn by Vitaliano

Factors that induce degradation:

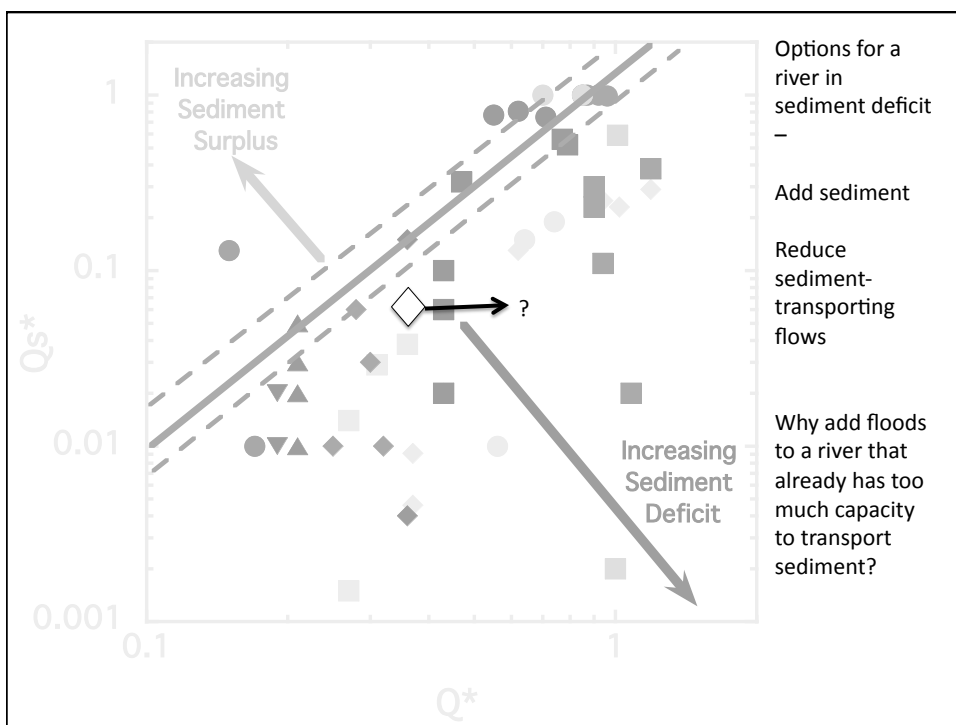
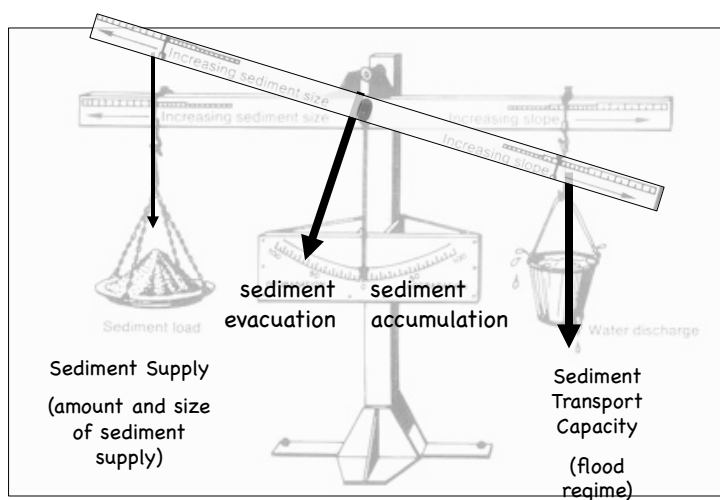
decreased sediment supply

Factors that induce aggradation:

less stream flow; smaller floods

increased grain size of sediment  
supply

## Most of Grand Canyon has been perturbed into a condition of sediment deficit



[The 1996 HFE] was conducted to **demonstrate management utility**. At the same time, the flood was a **manipulative experiment** to test specific ideas about what had been learned about the physics of flow, sediment transport, and sediment deposition. As a management demonstration, the flood might have resulted in failure: that is, the expected beneficial effects might not have been realized. As a manipulative experiment, the flood could not fail, because no matter what happened new knowledge would have been gained as long as appropriate observations were made. Ideas would have been either reinforced and understood more certainly because the result was as expected and the causes and effects more clearly documented, or concepts would be rejected, and knowledge would have changed because the results were not as expected. In fact, science proceeds most certainly when incorrect ideas are rejected.”

(Marzolf et al., 1999)

As a management action, there were six primary objectives of the 1996 HFE:

- remove nonnative fish,
- rejuvenate low velocity habitats for native fishes,
- enlarge sand deposits at relatively high elevation,
- preserve and restore sandbars used as campsites (0.3 to 1 m sand deposition on most sandbars ),
- reduce near-shore vegetation,
- provide water to the upper riparian zone vegetation (Schmidt and others, 1999a; Patten and others, 2001).

These objectives were to be accomplished without significant adverse impacts to the tailwater rainbow trout fishery, endangered species, cultural resources, or the regional economy.

The 2004 HFE was described as “an attempt to rebuild beaches” (U. S. Department of the Interior, 2002), but the magnitude of the peak flow was partly established to provide “greater scientific strength” by having a magnitude “more directly compared” to the 1996 HFE (U. S. Department of the Interior, 2002).

the 2004 HFE was “expected to create sandbars more efficiently and with a more diverse grain size distribution than did the 1996 ... [HFE] and is expected to transport a smaller percentage of sediment downstream than in 1996”

The sandbars thus created would likely be more resistant to erosion and retain more nutrients than coarser grained sandbars” (U. S. Department of the Interior, 2002).

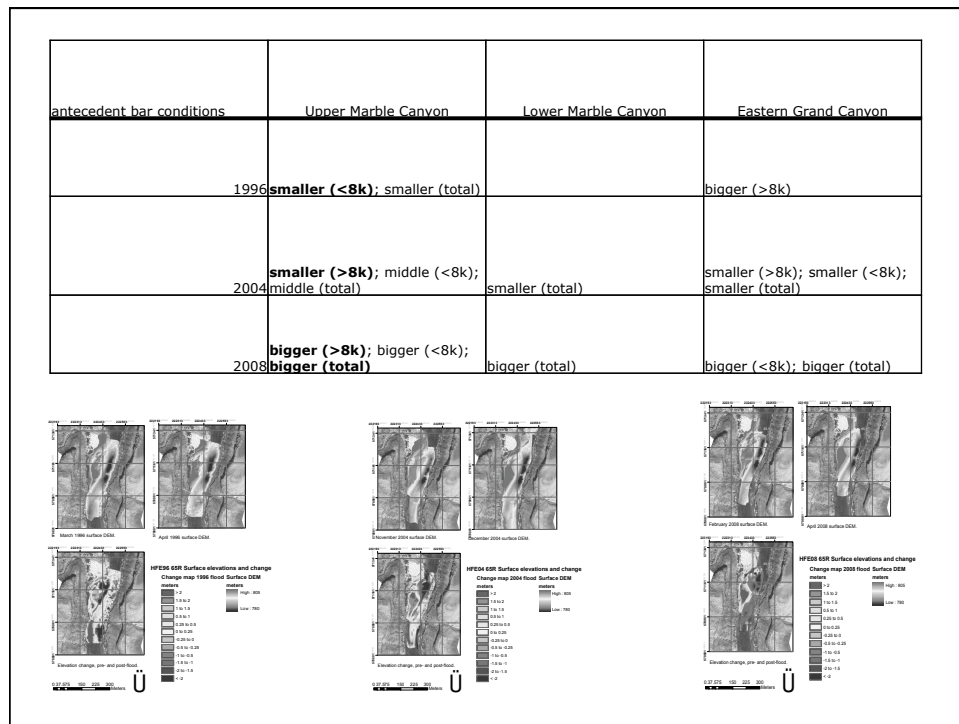
Research studies conducted during the HFE fall into two groups: “process/response studies” and “negative-impact studies” (Marzolf and others, 1999).

#### Antecedent sand enrichment

Conditions during the year before each HFE					
	Paria River sand supply (mmt)	Little Colorado River sand supply (mmt)	Median dam release (ft <sup>3</sup> /s)		
1996	0.38	0.04	<b>15,400</b>		
2004	0.63	0.19	10,500		
2008	<b>0.92</b>	<b>1.12</b>	11,300		

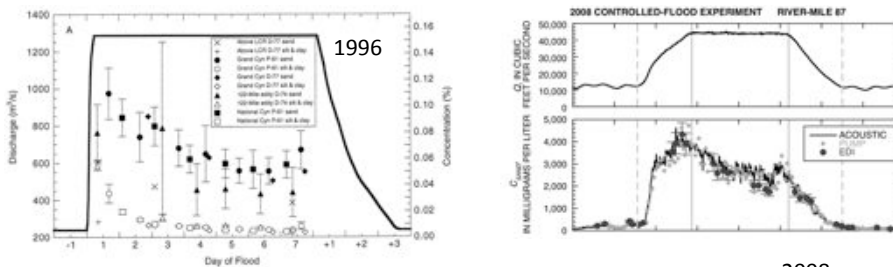
	Paria River	tributaries	Upper Marble Canyon $\Delta S$	RM 30 transport	tributaries	Lower Marble Canyon $\Delta S$	RM 61 transport
1996 (3.2 yrs)	> 0.38						
2004 (4.5 mths)	0.617	0.062	0.275-0.491	0.296	0.044	0.066-0.162	0.226
2008 (3.5 yrs)	3.35	0.335	<b>0.567-1.823</b>	2.49	0.096	0.259-0.811	2.051
			$\Delta S$ per kilometer			$\Delta S$ per kilometer	
2004			0.0059-0.011			0.0013-0.0032	
2008			<b>0.012-0.039</b>			0.0052-0.016	

RM 61 transport	Little Colorado River	tributaries	Eastern Grand Canyon $\Delta S$	RM 87 transport	tributaries	Middle and Western Grand Canyon $\Delta S$	RM 225 transport
	> 4.2						
0.226	0.18	0.037	<b>between -0.062 and 0.034</b>	0.481	0.102	0.06-0.252	0.427
2.051	3.021	0.081	0.174-1.498	4.317	0.372	0.522-1.312	3.586
			$\Delta S$ per kilometer			$\Delta S$ per kilometer	
			<b>between -0.0015 and 0.00081</b>			0.00027-0.0011	
			0.0042-0.036			0.0024-0.0059	



Trying to fix a river that is in sediment deficit by managing the tiny amount of available sediment replenished from the Paria River – it is hard!!

*These floods can only be scheduled when there is an available new supply from tributaries. Controlled flood releases can only be of short duration because the supply of sediment available for transport runs out.*



*Change in suspended sediment concentration with time during two large dam releases*

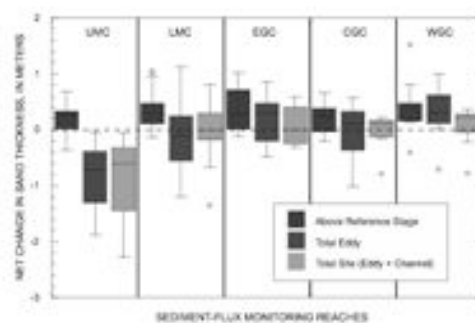
*Topping, Rubin, various papers*

2008

Topping et al., 2010

## Comparisons of transport during the HFEs

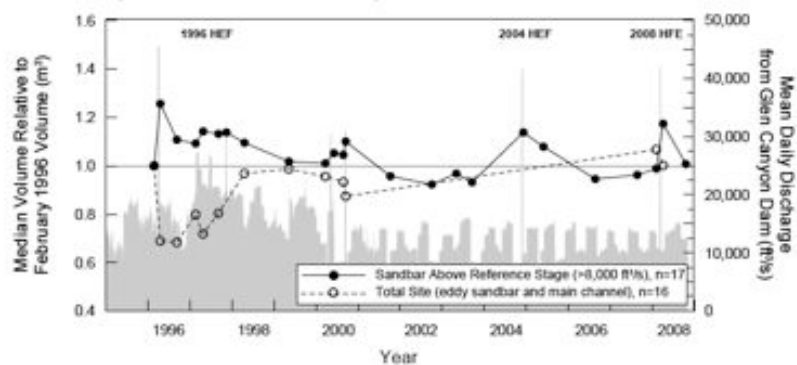
- 1) average suspended sand concentrations in 2008 were as high, or higher than during the previous two HFEs;
- 2) average suspended sand concentrations were as low, or lower during the 1996 HFE, except at RM 87;
- 3) average grain size of the suspended sand was finest at and downstream from RM61 during the 2008 HFE
- 4) average suspended mud concentrations were greater during the 2008 HFE than during other HFEs



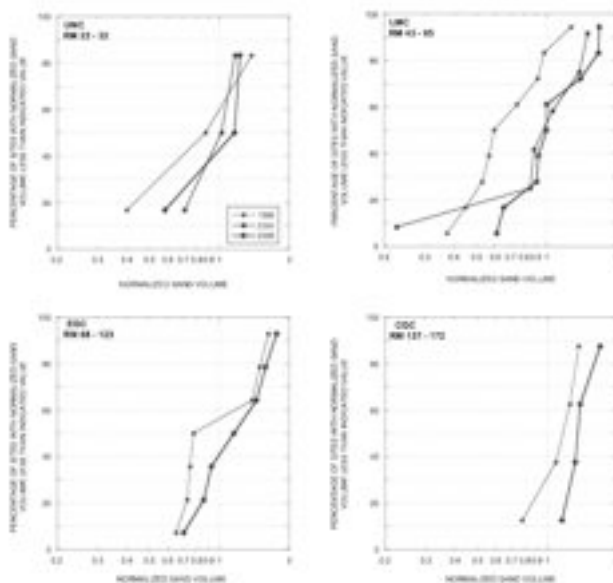
2008 HFE

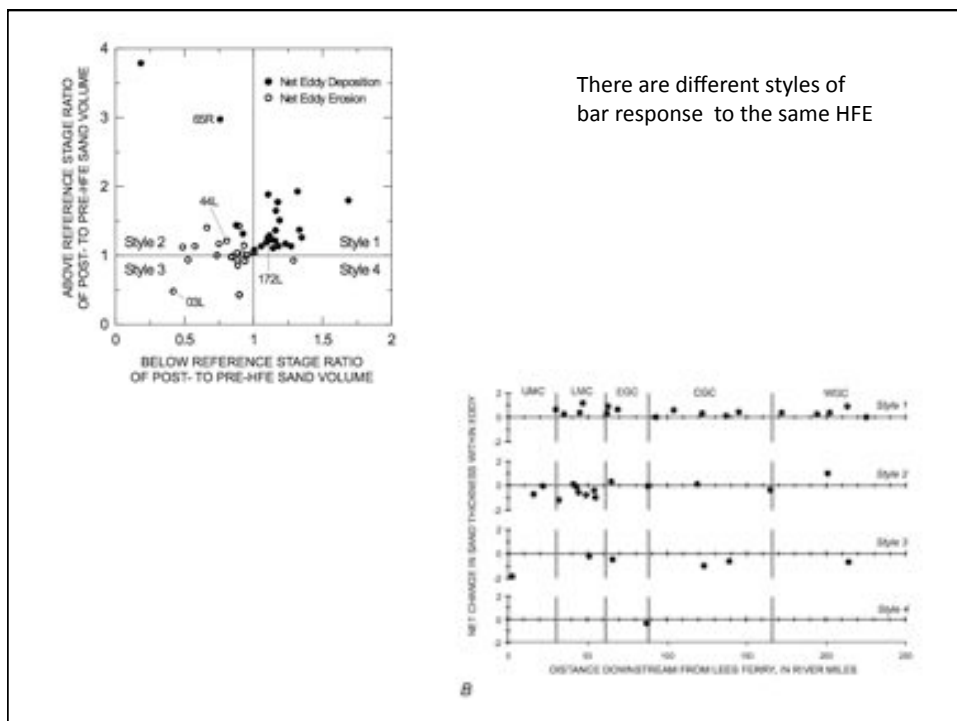
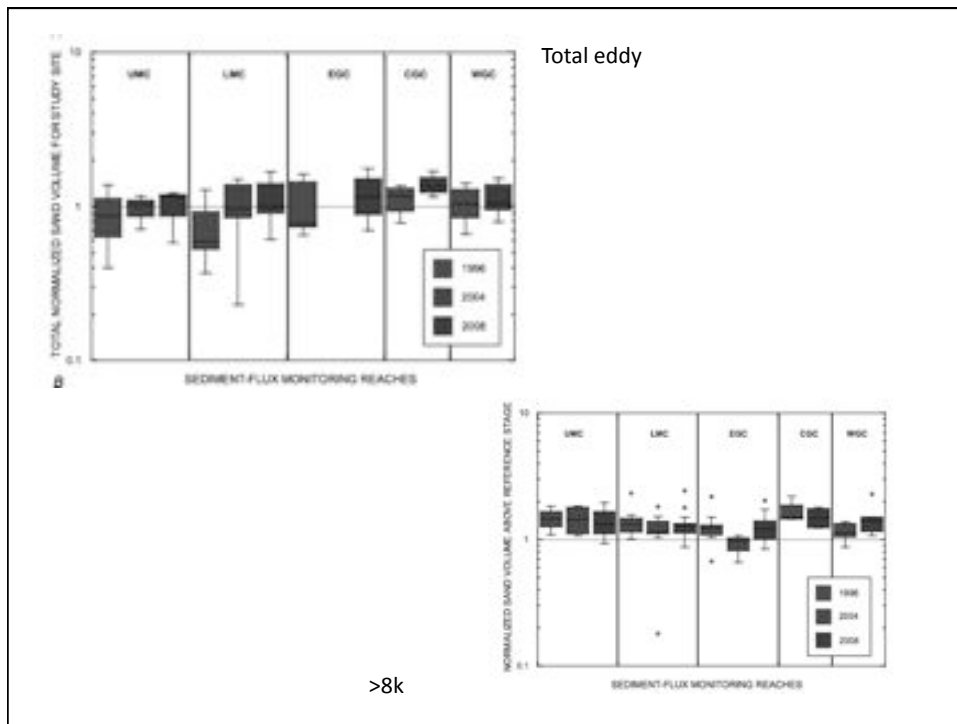
## Long-term. Large-scale perspective on sand bar changes

Marble Canyon and Eastern Grand Canyon



(NAU Geology, written comun.)





Grapevine, RM 81.76L, Downstream View:  
1976-1985-1989-2008 comparison



Late afternoon, August 7, 1976 (~daily mean  
 9,000 ft<sup>3</sup>/s)



1300 August 7, 1985 (~21,300 ft<sup>3</sup>/s)



1645 January 24, 1989 (~13,600 ft<sup>3</sup>/s)



0945 April 6, 2008 (~10,400 ft<sup>3</sup>/s)

Grapevine, RM 81.76L, Downstream View:  
1976, 1985, 1989 sand levels shown in 2008 photo



0945 April 6, 2008 (~10,400 ft<sup>3</sup>/s)

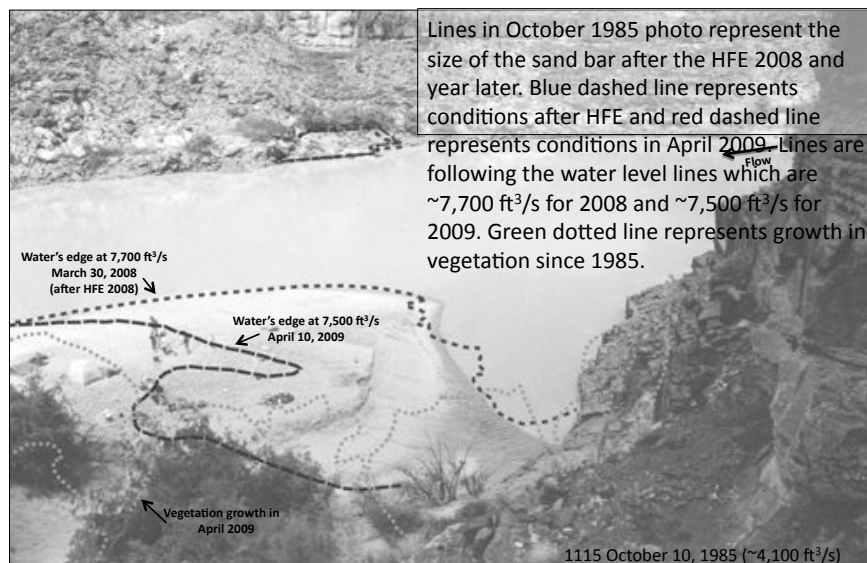
19 Mile Canyon RM 19.41L:  
1973-1985-2008 comparison



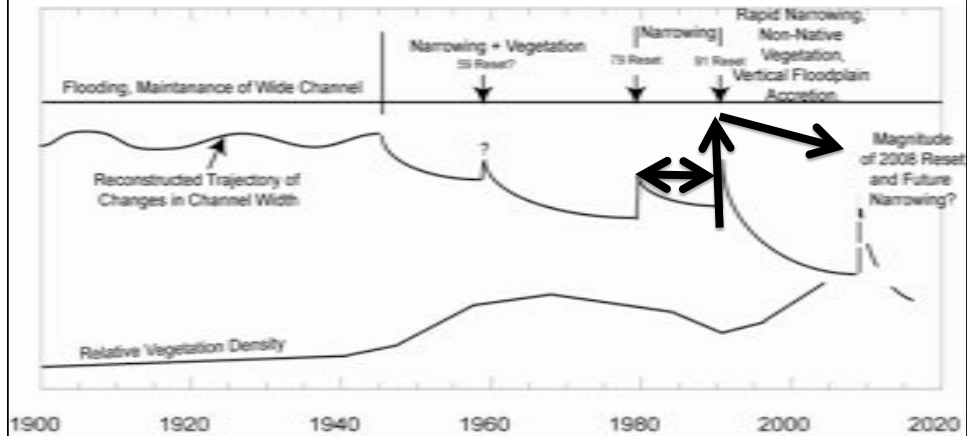
1973

1115 October 10, 1985 (~4,100 ft<sup>3</sup>/s)1100 March 30, 2008 (~7,700 ft<sup>3</sup>/s)0900 April 10, 2009 (~7,500 ft<sup>3</sup>/s)

19 Mile Canyon RM 19.41L:  
1985-2008-2009 comparison



Las opciones de rehabilitación: **aumentar la eficacia de las inundaciones** en la ampliación del canal, **incrementar la frecuencia de las inundaciones** que amplían el canal, **disminuir la tasa de estrechamiento** después de la inundación.



De estas opciones, el aumento de la eficacia de las inundaciones (por medio de eliminación de la vegetación) y la disminución de la tasa de estrechamiento después de la inundación (provisionando inundaciones uniformes) son opciones viables